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(54) Information recording device.

(57) An information recording device (Fig. 1) is disclosed, which device comprises write means (3, 8) for providing the record carrier (1) with information patterns (58, 59). The write means (3, 8) are adjustable. In determining the optimum adjustment a calibration procedure is carried out. For different settings of the write means (3, 8) information patterns (58, 59) are recorded. The optimum setting is determined on the basis of the recorded information patterns. The information recording device further comprises storage means for storing in a memory the determined optimum setting together with identification data which indicate for which combination of the recording device and a record carrier (1) the adjustment data has been determined. After a record carrier (1) has been loaded into the information recording device, it is detected whether adjustment data for the relevant combination of a record carrier (1) and an information recording device has been stored in the memory (1, 12). If adjustment data for said combination has been stored the write means (3, 8) are adjusted in conformity with this data and no new calibration procedure is performed, which saves a substantial amount of time.

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INFORMATION RECORDING DEVICE.

The invention relates to an information recording device comprising write means for providing the record carrier with information patterns, means for determining record carrier dependent adjustment data, adjustment means for adjusting the write means in conformity with the determined adjustment data, the means for determining the adjustment data being adapted to record information patterns for different settings of the write means and to determine, on the basis of the recorded information pattern, the adjustment data in accordance with a predetermined criterion.

Such a device is known from US 4,631,713. In the known device the adjustment data is determined every time that the record carrier is introduced into the device. A drawback of the known device is that it takes a comparatively long time to determine the optimum adjustment.

It is an object of the invention to provide a device as defined in the opening paragraph, which requires less time to determine the optimum adjustment of the write means.

According to the invention this object is achieved in that the information recording device further comprises storage means for storing in a memory the determined adjustment data together with identification data indicative of the combination of the recording device and the record carrier for which the adjustment data has been determined, and detection means for detecting, after insertion of a record carrier into the information recording device, whether adjustment data for the relevant combination of a record carrier and information recording device has been stored in the memory, the adjustment means being adapted to adjust the write means in conformity with the adjustment data in the case that adjustment data for the said combination has been stored. The invention is based on inter alia the recognition of the fact that the optimum adjustment of the write means is found to change hardly in the course of time.

As a result of the storage of the adjustment data and the identification data in a memory the adjustment has to be determined only once for a specific combination of a record carrier and an information recording device, so that the time required for determining the adjustment data is also minimised.

It is possible to assign a device identification code to the information recording device and to provide the recording device with means for recording the device identification code together with the adjustment data on the record carrier. However, it is preferred to use an embodiment of the information recording device, which is characterized in that the storage means are adapted to store in a memory of the information recording device the determined adjustment data together with the record carrier identification code indicative of the record carrier for which the data has been determined, the recording device comprising read means for reading a record carrier identification code which may be present on the record carrier, the detection means being adapted to determine whether adjustment data for the record carrier identification thus read has been stored in the memory of the device. The last-mentioned embodiment has the advantage that the adjustment data occupies a minimal space on the record carrier. This is particularly so if the same record carrier is used in more than one recording device. In the last-mentioned embodiment it is then adequate to record only one record carrier identification on the record carrier, while in the case that a device identification is recorded for each of the information recording devices used a device identification and the adjustment data should be recorded on the record carrier. In principle, the record carrier identification can be applied during manufacture of the record carrier. In the case of optical record carriers this is possible in that the master employed in the fabrication of the record carriers is provided with an identification pattern. The problem which then occurs is that a complete series of the record carriers has the same record carrier identification code. Since the recording parameters of the record carriers may vary within one series of record carriers it is possible that if two record carriers of the same series are employed in the same information recording device the information patterns are not recorded in an optimum manner for both record carriers.

An embodiment of the information recording device which mitigates this drawback is characterized in that the device comprises means for providing the record carrier with a record carrier identification. Preferably, the information recording device then comprises a random-code generator for generating the record carrier identification to be recorded. This minimizes the likelihood of the same record carrier identification being recorded in the case of mass or series produced information recording devices. Thus the likelihood of a non-optimum adjustment when the same record carrier is used in different information recording devices is minimized.

The device in accordance with the invention is particularly suitable for use in apparatus in which the linear velocity with which the record carrier is scanned during the recording of the information

patterns is constant. In that case the changes in the recording conditions are minimal, so that a previously determined optimum adjustment of the write means need not be adapted.

However, the invention is not limited to device with a constant linear scanning velocity during recording. It can also be employed in systems with variable scanning velocities, in which the scanning velocity has no influence or a predictable influence on the adjustment of the write means.

Further embodiments of the recording device and the advantages thereof will now be described in more detail with reference to Figs. 1 to 11, in which

Figs. 1 and 9 show embodiments of the information recording device in accordance with the invention;

Figs. 2 and 10 are flow charts of programs carried out by a control unit in the devices shown in Figs. 1 and 9;

Fig. 3 shows a suitable format for recording a record carrier identification code;

Fig. 4 shows a suitable position for recording the record carrier identification code;

Figs. 5, 6 and 7 by way of illustration show a possible calibration procedure for determining an optimum adjustment;

Fig. 8 shows an example of an analysis circuit for use in the information recording device, and

Fig. 11 is a flow chart for a calibration program which can be carried out by the control unit for the information recording device.

Fig. 1 by way of example shows an embodiment of an information recording device in accordance with the invention. The present embodiment is a recording device by means of which information can be recorded on a record carrier 1, for example an optical record carrier, which is rotated about an axis 2. The information recording device comprises a customary write head 3, arranged opposite the rotating record carrier 1. By means of a customary positioning system, for example in the form of a motor 4 and a spindle 5, the read-write head 3 can be moved in a radial direction relative to the record carrier 1 under control of a customary control unit 6, which comprises for example a microprocessor.

An information signal Vi to be recorded can be applied to a signal processing circuit 7 via an input 6. The signal processing circuit 7 is of a customary type, which converts the applied input signal into a recording signal Vop of a suitable recording format, for example a CD format. The recording signal Vop is applied to a driver circuit 8 of a customary type, which converts the recording signal Vop into a drive signal Vs for the read/write head 3 in such a way that an information pattern corresponding to the recording signal Vop is recorded on the record carrier. For the purpose of reading the recorded information patterns the read/write head 3 has an output for supplying a read signal VI which is representative of the information pattern being read. The read signal VI is applied to a read circuit 9 for recovering the information represented by the read signal. The driver circuit 8 is of an adjustable type, enabling one or more of the parameters with which the quality of the recorded information pattern can be influenced to be adjusted. When an optical read/write head is used by which an information pattern of optically detectable effects is formed by means of a radiation beam, the intensity of the radiation beam is an important parameter which largely dictates the quality of the information pattern. If the read/write head is a magnetic or magneto-optical write head which generates a magnetic field for the purpose of forming an information pattern in the form of magnetic effects (domains), the field strength of the generated magnetic field may be an important adjustment parameter.

If the information pattern is formed by means of write pulses the pulse width may be an important adjustment parameter. It is to be noted that the above-mentioned adjustment parameters are only few examples of the large number of adjustment parameters which are possible. In this respect reference is made in particular to NL-A- 9000150 (PHN 13.217), in which the adjustment parameter is a reference value for the speed with which the effects are formed. During the formation of the effects the intensity of the write beam is controlled to maintain the speed with which the effects are formed at the adjusted reference value.

For determining the optimum adjustment of the driver circuit 8 the device comprises an analysis circuit 10, which derives from the read signal an analysis signal which is indicative of the quality of the information pattern being read. The optimum adjustment can be determined by forming test information patterns on the record carrier 1 for different settings of the driver circuit and by selecting, on the basis of the analysis signal Va, that setting for which the analysis signal indicates an optimum quality. In principle, the information signal Vi may be employed for writing the test information pattern. However, it is also possible to employ a test signal generator 11 for this purpose, which may then be included, for example, in the signal processing circuit 7. The optimum adjustment is determined under control of the control unit 15, which for this purpose is coupled to the analysis circuit 10, to the driver circuit 8, and to the test signal generator 11, if present, which control unit is loaded with a suitable program or comprises a suitable hardware circuit. Preferably, the optimum adjustment is determined in a calibration procedure,

which is carried out after a record carrier has been inserted in the information recording device for the first time. The optimum adjustment data and the identification data which are indicative of the combination of a record carrier and recording device are subsequently stored. When the same record carrier is reinserted into the recording device the stored adjustment data can then be employed again, so that it is not necessary to carry out a new calibration procedure. This saves a considerable amount of time.

With respect to the storage of adjustment data it is to be noted that this adjustment data may be stored both on the record carrier itself and in a memory 12 of the information recording device. When the adjustment data is stored on the record carrier identification data in the form of a device identification can be recorded together with the adjustment data. After a record carrier has been loaded into the information recording device it is then possible on the basis of the device identiciation recorded on the record carrier to detect unambiguously whether the adjustment data has already been determined for the relevant combination of a record carrier and an information recording device. If this is the case a calibration procedure is not necessary and the driver circuit 8 can be adjusted in conformity with the adjustment data associated with the device identification.

Although in the above method of storing the adjustment data it is always possible to determine unambiguously whether the adjustment data has already been determined in a previous calibration procedure, this method has the disadvantage that the amount of space occupied on the record carrier by the adjustment data and the device identification codes may be substantial. This is particularly so if the same record carrier is employed in a large number of information recording devices. Indeed, in that case every information recording device will record its own adjustment data and device identification code on the record carrier.

This drawback is mitigated if the record carrier is provided with a record carrier identification code and the identification data in the form of a record carrier identification code and the associated adjustment data are stored in the information recording device.

In principle, the record carrier can be provided with the record carrier identification code during manufacture. This has the drawback that it often allows only those methods to be used in which always complete series of record carriers are provided with the same record carrier identification code. If in such a case two or more record carriers are employed in the same information recording device it is not unlikely that on account of the usual differences between the recording parameters of the record carriers the write circuit 8 is not optimised for all the record carriers of the same series. Therefore, it is preferred to apply the record carrier identification code by means of the first information recording device in which it is used. Preferably, the record carrier identification code to be recorded is a random generated code. This minimises the likelihood that the same record carrier identification code is generated for different record carriers when two or more information recording devices of the same make and type are used.

To determine the random record carrier identification code the information recording device may be provided with a random code generator 13. The random code generator 13 may comprise, for example, a noise source whose output signal is sampled and is digitised by means of a digital-to-analog converter. The random code generator may alternatively comprise a cyclic counter which counts the pulses of a high-frequency clock signal. However, other code generators are also possible, such as for example one of a type realised by means of software included in the software of the control unit 51.

Fig. 2 is a flow chart of a program for determining and storing the adjustment data in the case that the record carrier is provided with a record carrier identification and that the identification data and the associated adjustment data are stored in the memory 12 of the information recording device.

The flow chart comprises a step A11 in which a record carrier identification which may be present on the record carrier is read under control of the control unit 5. Under control of the control unit 5 the read/write head 3 is then moved to a record carrier area intended for recording the record carrier identification code. In a step A12 it is ascertained whether adjustment data has been stored in the memory 12 for the record carrier identification read. If this is so a step A13 is carried out, in which the driver circuit 8 is adjusted in conformity with the adjustment data associated with the record carrier identification code read. In the absence of adjustment data a calibration procedure is carried out in a step A14, to determine the optimum setting. An example of the calibration procedure will be described in more detail hereinafter.

After the calibration procedure has been carried out it is ascertained in a step A15 whether the record carrier 1 has already been provided with a record carrier identification code. If this is the case, the record carrier identification code together with the adjustment data is stored in the memory 12 in a step A16, for example in a table in which a plurality of combinations of record carrier identification codes and adjustment data can be stored. Subsequently, the program proceeds with the step

A13 described above. If during the step A15 it is found that the record carrier 1 has not yet been provided with a record carrier identification code a new record carrier identification code is generated by means of the random code generator 13 in a step A17. If desired, it is also checked whether this code occurs in the table in order to prevent the same record carrier identification code being assigned to two record carriers. The newly generated record carrier identification code is recorded on the record carrier at a location from which it can be retrieved. When a record carrier provided with address information is used it is possible to employ for this purpose a record carrier part having a predetermined address. However, alternatively this information may be recorded at a predetermined location on the record carrier, for example at a predetermined distance from the centre of rotation of the record carrier. In the case that the information is recorded at a location having a predetermined address, the information recording device should comprise an address detection circuit 15 for determining the addresses, which circuit recovers the address information from the read signal VI and supplies the recovered address information to the control unit 5. During recording of the record carrier identification code the read/write head 3 is positioned under control of the control unit 5 in a customary manner, for example on the basis of the received address information, opposite to the area intended for recording the record carrier identification code and, subsequently, the read/write head 3 is set to a write mode and an information signal Vident, which is representative of the record carrier identification code, is applied to an input of the signal processing circuit 7. The signal processing circuit 7 then converts the signal Vident into a recording signal suitable for recording and a corresponding identification pattern is recorded on the record carrier 1.

After termination of the step A17 the program proceeds with the steps A16 and A13 already discussed. After the step A13 recording of the signal Vi can be started under optimum conditions in a step A18.

In the foregoing an embodiment of the information recording device has been disclosed which is suitable for recording information on a disc-shaped record carrier. However, it is to be noted that the scope of the invention is not limited to such recording devices. It may also be applied to recording devices in which the information is recorded on a tape, for example a magnetic tape.

Moreover, it is to be noted that the calibration procedure to be used for determining the optimum adjustment data depends on the recording principle employed in the information recording device. For a number of different calibration procedures suitable for use within the scope of the present invention reference is made to Netherlands Patent Applications NL-A-8901345 (PHQ 89.016), NL-A-8901591 (PHN 12.994), and NL-A-900150 (PHN 13.217), herewith incorporated by reference. The optimum location for recording the record carrier identification code and the form in which the identification code is recorded depend strongly on the type of the record carrier used and on the format to which the information signal is converted for the purpose of recording. In a device for recording a standard CD signal it is preferred to insert the record carrier identification code to be recorded in the subcode Q-channel of the CD signal. In that case the record carrier identification code can be extracted simply from the read signal by means of a subcode detector as customarily used in CD players. This is in contradistinction to the case in which the record carrier identification code is included in the main channel of the CD signal. In the last-mentioned case determining the record carrier identification code requires additional hardware. A suitable format for the record carrier identfication code in the subcode Q-channel is shown in Fig. 3. In this format a plurality of bits 30 in a frame 31 of the subcode Q-channel serve to indicate the record carrier identification code. A suitable record carrier for recording standard CD signals is described in NL-A-8901591 and NL-A-8900766 (PHN 12.994 and PHN 12.887). Such a record carrier has a spiral servotrack which is intended for information recording. The servotrack has a track modulation, for example a frequency-modulated track wobble, representing addresses in the form of absolute time codes ATIP. The servotrack is divided into a plurality of areas as indicated in Fig. 4. In this Figure the spiral track is shown diagrammatically as a straight line and bears the reference numeral 40. The servotrack 40 comprises an area PA (Program Area) intended for recording information signals, such as for example digitised audio signals, an area LI (Lead In) intended for recording a table of contents ("TOC") as prescribed by the CD standard, an area PMA which is intended for recording a temporarly table of contents as described in NL-A-8900766 (PHN 12.887), and an area PCA intended for recording test information patterns for the purpose of determining the optimum adjustment data. The start addresses of the areas PCA, PMA, LI and PA are designated TPCA, TPMA, TLI and TPA respectively. In the layout of the servotrack 40 as shown in Fig. 4 particularly the areas PCA and PMA are suitable for recording the record carrier identification code. By way of example two suitable areas 41 and 41a are indicated in Fig. 4. Hereinafter the area 41 will be referred to as the identification area IA and the address of this area will be designated TIA. The areas 41 and 41a,

which are situated outside the areas LI and PA, have a format as prescribed by the CD standard for "read-only" discs. This has the advantage that the read-out of a record carrier of the inscribable type on which a standard CD signal has been recorded is not disturbed by thepresence of the record carrier identification code if reading is performed by a read device intended for reading "Compact Discs" of the "read-only" type.

Hereinafter an embodiment of the recording device in accordance with the invention will be described, by way of example, for recording information on the optical record carrier described above. First of all, a suitable method of determining the optimum adjustment data will be explained. An optically readable record carrier may be provided with an information pattern comprising effects having varying reflection properties by scanning the record carrier with a radiation beam whose intensity I is switched between a low level Il, for which there are no changes in reflection, and a high write level Is, which produces a change in reflection in the scanned part of the record carrier. Fig. 5 gives an example of such an intensity variation and the associated pattern of effects 58 having changed reflection properties and intermediate areas 59 having unchanged properties. The information pattern of effects 58 and intermediate areas 59 can be read by scanning the pattern with a read beam of a constant intensity, which is low enough to preclude a detectable change in optical properties. During the scanning process the read beam reflected from the record carrier is modulated in conformity with the information pattern being scanned. The modulation of the read beam can be detected in a customary manner by means of a radiation-sensitive detector, which generates a read signal Vl which is indicative of the beam modulation. The read signal Vl is also shown in Fig. 5. The read signal Vl is reconverted into a bivalent signal by comparison of the read signal with a reference level Vref. For a reliable conversion it is desirable that the points where the read signal Vl intersects the reference level are well-defined, in other words, the "jitter" in the read signal Vl should be minimal. As is known, jitter of the read signal Vl in optical recording is minimal if the information pattern is symmetrical, i.e. if the average length of the effects 58 is equal to the average length of the intermediate areas 59. The problem which then arises is that the length of the effects 58 strongly depends on the write intensity Is. If the write intensity is too high the effects 58 will be too long and if the write intensity is too low the effects 58 will be too short. Therefore, an accurate adjustment of the write intensity is required. A method of determining the optimum write intensity will be described in more detail with reference to Fig. 6. Figs. 6a, 6b and 6c show the intensity variation I, the corresponding information pattern of effects 58 and intermediate areas 59, and the read signal Vl in the case that the write intensity Is is too low, optimum and too high respectively.

In Fig. 6 the read signals Vl vary between a maximum level A1 and a minimum level A2. The level DC represents the value of the d.c. level in the read signal Vl. As will be apparent from Fig. 6 the d.c. level DC of the read signal Vl is substantially centred between the levels A1 and A2 if the write intensity has the optimum value. If the write intensity is too low the d.c. level DC will be situated above the middle between the levels A1 and A2, while in the case that the write level is too high the d.c. level DC will be situated below the middle between the levels A1 and A2. Thus, an optimum write intensity can be obtained by adjusting the write intensity Is to a value for which the d.c. level DC is situated substantially in the middle between the levels A1 and A2.

An improvement of the above method of determining the optimum intensity will be described with reference to Fig. 7a. In accordance with this method an information pattern is recorded for the purpose of determining the optimum intensity, which pattern comprises a plurality of subpatterns 70 each comprising a short effect 58 and a short intermediate area 59, recorded by means of a write signal having a 50% duty cycle. The information pattern further comprises a second subpattern 71 comprising a comparatively long effect 58 and a comparatively long intermediate area 59, also recorded with the aid of a write signal having a 50% duty cycle. The number of subpatterns 70 is selected to be substantially larger than the number of subpatterns 71. Fig. 7a further shows the read signal Vl obtained in the case of reading with the aid of an optical read device.

The dimensions of the subpatterns 70 are selected in such a way that the amplitude of the signal components in the read signal Vl corresponding to said subpatterns 70 is substantially smaller than the amplitude of the signal components corresponding to the subpatterns 71. This can be achieved by selecting the dimensions of the subpatterns 70 in such a way that only the 1st harmonic of this pattern is situated below the optical cut-off frequency of the optical scanning device. The dimensions of the subpattern 71 are selected in such a way that at least the 1st and the 2nd harmonic of this pattern are situated below said optical cut-off frequency. The d.c. level DC in the read signal Vl is dictated mainly by the signal components corresponding to the subpatterns 70. The difference between the maximum value A1 and the minimum value A2 of the read signal Vl is dictated exclusively by the value corresponding to

the subpattern 71. As a change in write power Is has a substantially greater influence on the ratio between the lengths of the effects 58 and the intermediate areas 59 of the subpatterns 70 than on the ratio between said lengths for the subpatterns 71, the d.c. level DC in the case of the method illustrated in Fig. 4 will also be far more susceptible to write level variations than in the case of the method illustrated in Fig. 6, where the amplitude of the read signal Vl is the same for all the subpatterns occurring in the information pattern. All this means that the optimum write power can be determined far more accurately by means of the method illustrated in Fig. 7a.

In addition to the information pattern shown in Fig. 7a, which has been recorded with an optimum write intensity, similar information patterns are shown in Figs. 7b and 7c, which have been recorded at a write level which is too low and which is too high respectively. As will be apparent from Fig. 7, the d.c. level DC in the case of the optimum write intensity is again substantially centred between the maximum signal value (A1) and the minimum signal value (A2) in the signal Vl, while in the case of a write level which is too low or too high the d.c. level DC is situated above and below the centre respectively. The information pattern shown in Fig. 7 is only one of the possible information patterns comprising a comparatively large number of subpatterns comprising short effects and intermediate areas and a comparatively small number of sub patterns comprising long effects and intermediate areas. A subpattern which is also very suitable is a pattern corresponding to an EFM signal in conformity with the CD standard. Such a pattern comprises areas of a length corresponding to at least 3 bits (I3 effect) and at the most 11 bits (I11 effect). Approximately one third of all the effects in such an EFM pattern are I3 effects, whereas only 4 % of all the effects are I11 effects. The dimensions of the I3 effects are such that only the fundamental of these effects is situated below the optical cut-off frequency of the optical read system. Of the I11 effects at least the 1st, the 2nd and the 3rd harmonic are situated below the optical cut-off frequency.

Fig. 8 shows an example of the analysis circuit 10 by means of which an analysis signal Va can be derived from the read signal Vl to indicate the extent to which the d.c. level DC deviates from the level corresponding to the optimum write intensity. The analysis circuit 10 in Fig. 8 comprises a low-pass filter 80 for determining the d.c. level DC in the read signal Vl. The analysis circuit 10 further comprises a positive-peak detector 81 for determining the maximum value A1 in the read signal Vl and a negative-peak detector 82 for determining the minimum value A2 in the read signal Vl. The output signals of the peak detectors 81 and 82 are applied to non-inverting inputs of an adder circuit 83, while the output signal of the low-pass filter 80, after amplification to twice its value, is applied to an inverting input of the adder circuit 83, so that the output signal of the adder circuit, which signal constitutes the analysis signal Va, complies with Va = A1 + A2 - 2DC and consequently indicates the extent to which the signal value DC deviates from the mean value of the maximum signal value A1 and the minimum signal value A1.

For other suitable examples of analysis circuits reference is made to NL-A-8901591 (PHN 12.994).

Fig. 9 shows in detail an embodiment of an information recording device for recording standard CD signals. In this Figure elements corresponding to the elements already described bear the same reference numerals. The recording device shown comprises drive means in the form of a motor 100 and a turntable 101 for rotating a radiation-sensitive record carrier 1 about the axis 2, which record carrier is of a type on which address information has been recorded as a track modulation of the servo track. The track modulation may be a track wobble, the frequency of the wobble being modulated in conformity with a position information signal comprising absolute time codes ATIP. The read/write head 3 is of a customary type comprising a semiconductor laser for generating a radiation beam 107a whose intensity is adjustable by means of the driver circuit 8. In known manner the radiation beam 107 is aimed at the servo track of the record carrier 1. The beam 107a is then reflected partly from the record carrier 1, the reflected beam being modulated in conformity with the track wobble and, if an information pattern has been recorded, also in conformity with the information pattern. The reflected beam is directed towards a radiation-sensitive detector 108a, which generates the read signal Vl corresponding to the beam modulation. The signal Vl comprises a component produced by the track wobble and having a frequency of approximately 22 kHz at the nominal constant linear scanning velocity. By means of a motor control circuit 108 for controlling the motor 100 the motor speed is controlled so as to maintain the frequency of the component produced by the track wobble in the read signal Vl at substantially 22 kHz, so that a constant linear scanning velocity is realised. The address detection circuit 15 is of a type which derives the time codes ATIP from the component produced in the read signal Vl by the track wobble and applies these codes to the control unit 5. Moreover, the read signal Vl is applied to an amplifier circuit 111 having a high-pass characteristic in order to reject the signal components produced in the read signal Vl by the track wobble. The read signal Vl, from which the low frequency

components have thus been removed, is applied to the analysis circuit 10. The signal processing circuit 7 further comprises a customary CIRC encoding circuit 112, to which the signal Vi to be recorded can be applied via a switch 11a which is controlled by the control unit 5. The CIRC encoding circuit 112 is arranged in series with a customary EFM modulator 113 which adds subcode information to the main information received from the CIRC encoder 112 and subsequently converts this information into an EFM modulated signal. For the subcode information the EFM modulator is coupled to the control unit 5. The EFM modulator 113 has its output connected to the driver circuit 8. The driver circuit 8 is of a controllable type. Depending on the control signals received from the control unit 5 the driver circuit 8 sets the intensity of the generated beam 107a to a constant low intensity Il or the driver circuit 8 switches the intensity of the beam between the low level Il and the write level Is in conformity with the EFM modulated signal received from the EFM modulator 113. Moreover, the write level Is can be adjusted by the control unit 5. For the purpose of recording the test information pattern the recording device shown in Fig. 9 comprises a signal generator 11, which comprises the switch 11a and the signal generator 11b. The signal generator 11b generates a random digital signal or a signal corresponding to the digital signal value zero (digital silence). The signal generated by the signal generator 11b is applied to the CIRC encoding circuit 112 via the switch 11a. The switch 11a is of a customary type, which depending on the control signal received from the control unit 5 transfers either the signal Vi to be recorded or the output signal of the signal generator 11b.

The read circuit 9 comprises an EFM demodulator 114 of a customary type, which reconverts the EFM words in the read signal Vl into information words and which separates the subcode information from the main information. The subcode information, in particular the subcode Q information, is applied to the microcomputer 110. The main information is applied to a CIRC decoder 115 of a customary type, which recovers the original information signal Vi from the main information received from the EFM demodulator 114. For determining the write intensity setting the control unit 5 is loaded with suitable program. Fig. 10 shows a flow chart of such a program, which substantially corresponds to the flow chart shown in Fig. 2 but in which a number of steps have been divided into substeps. The record carrier identification code, if any, is read in the step A11. Two substeps B1 and B2 are then carried out. In the step B1 the record carrier area with the start address TIA of the identification area IA is located under control of the control unit 5. Once this area is reached the control unit recovers the record carrier identification code from the subcode Q signal received from the read circuit 9. Subsequently, it is ascertained in the step A12 whether the adjustment data, specifically the optimum write-intensity setting Iopt, for this code has been stored in the memory 12. If this is the case the write intensity is set to the value Iopt under control of the control unit 5 in the step A13. If not, the optimum value Iopt for the write intensity is derived in A14 during a calibration program to be described in more detail hereinafter with reference to Fig. 11. After the step A14 it is ascertained in the step A15 whether the record carrier already has a record carrier identification code. If this is the case, the adjustment value together with the record carrier identification code is stored in the memory 12 in the step A16 and subsequently the program proceeds with the step A13.

In the other case the record carrier is provided with a record carrier identification code in the step A17. During this step the substeps B3 through B7 are carried out. In the step B3 a new record carrier identification code is generated by means of the random code generator 13. In the step B4 the identification area IA having the address TIA is located. Once this area is reached recording is started in the step B5 by setting the read/write head to the write mode. In the step B6 the new record carrier identification code is converted to the format required for the subcode Q-channel and is applied to the EFM modulator 113. Preferably, a plurality of subcode Q-frames with the record carrier identification code, for example 10, are recorded in succession, because this improves the reliability of reading the record carrier identification code at a subsequent instant. After said number of subcode Q frames with the record carrier identification code has been recorded the read/write head 3 is again set to the read mode in the step B7 and the program proceeds with the step A16.

Fig. 11 is a flowchart of the calibration program carried out in the step A14. In the step S1 a test area within the area PCA is selected in which the test information patterns can be recorded. The manner in which this can be effected is described in detail in inter alia the afore-mentioned NL-A-8901591 (PHN 12.994). In the step S2 the selected area is located under control of the control unit 5. Once this area is reached the write intensity Is is set to the initial value Io in the step S4. Preferably, the value of Io for the relevant record carrier is prerecorded on the record carrier in a manner as described in Patent Application NL-A-8901145 (PHN 12.925). This value can then be read prior to the set-up cycle. Moreover, under control of the control unit 5 the signal generator 11b is connected to the CIRC encoding circuit 112 by means of the controllable switch 11a, so that an EFM modulated

test signal, determined by the output signal of the signal generator, is generated by the EFM modulator 113. Finally, in the step 54 the read/write head 3 is set to the write mode, which results in a test information pattern corresponding to an EFM signal being recorded. In the step S5 the absolute time code ATIP detected by the address detection circuit 15 is read by the control unit 5. In the step S6 it is ascertained whether this absolute time code has changed relative to the previous read-out. If this is not the case, the step S5 is repeated. If it has changed, it is tested in the step S7 whether the absolute time code being read indicates the end of the test area. If this is not the case the step S8 is performed, in which the write intensity Is is incremented by a small step ΔI, after which the program proceeds with the step S5. If in the step S7 it is found that the end of the test area is reached the step S9 is performed, in which the read/write head 3 is again set to the read mode. In the step S10 the beginning of the test area just described is located again and is read. In the step S11 the analysis signal Va is read by the control unit 5. In the step S12 it is checked whether the value of the analysis signal Va corresponds to the optimum write intensity. If this is not the case, the program proceeds with the step S11. In the other case the absolute time code detected by the address detection circuit 15 is read out in the step S13. Subsequently, in the step S15, the optimum write intensity corresponding to the absolute time code read in the step S13 is computed. This is possible, for example, by determining the difference between the absolute time code last read and the time code corresponding to the beginning of the test area. By means of this difference it is possible to determine by how many steps ΔI the initial value Io has been incremented before the absolute time code ATIP last read was reached during the recording of the test information pattern. This number of steps and the initial value Io define the optimum write intensity Iopt.

It is to be noted that the calibration procedure described herein is only one of the many procedures possible for optical record carriers of this type. Another very suitable calibration procedure for record carriers of this type is described in, for example, NL-A-900150 (PHN 13.217).

Claims

1. An information recording device comprising write means for providing the record carrier with information patterns, means for determining record carrier dependent adjustment data, adjustment means for adjusting the write means in conformity with the determined adjustment data, the means for determining the adjustment data being adapted to record information patterns for different settings of the write means and to determine, on the basis of the recorded information pattern, the adjustment data in accordance with a predetermined criterion, characterized in that the information recording device further comprises storage means for storing in a memory the determined adjustment data together with identification data indicative of the combination of the recording device and the record carrier for which the adjustment data has been determined, and detection means for detecting, after insertion of a record carrier into the information recording device, whether adjustment data for the relevant combination of a record carrier and information recording device has been stored in the memory, the adjustment means being adapted to adjust the write means in conformity with the adjustment data in the case that adjustment data for the said combination has been stored.

2. An information recording device as claimed in Claim 1, characterized in that the storage means are adapted to store in a memory of the information recording device the determined adjustment data together with the record carrier identification code indicative of the record carrier for which the data has been determined, the recording device comprising read means for reading a record carrier identification code which may be present on the record carrier, the detection means being adapted to determine whether adjustment data for the record carrier identification thus read has been stored in the memory of the device.

3. An information recording device as claimed in Claim 1, characterized in that the device comprises means for providing the record carrier with a record carrier identification.

4. An information recording device as claimed in Claim 3, characterized in that the recording device comprises a random-code generator for generating the record carrier identification code.

5. An information recording device as claimed in any one of the preceding Claims, characterized in that the write means comprise means for scanning the record carrier with a constant linear velocity by means of a write head, which write head, for the purpose of recording the information patterns, comprises means for realizing a detectable change in the record carrier area being scanned.

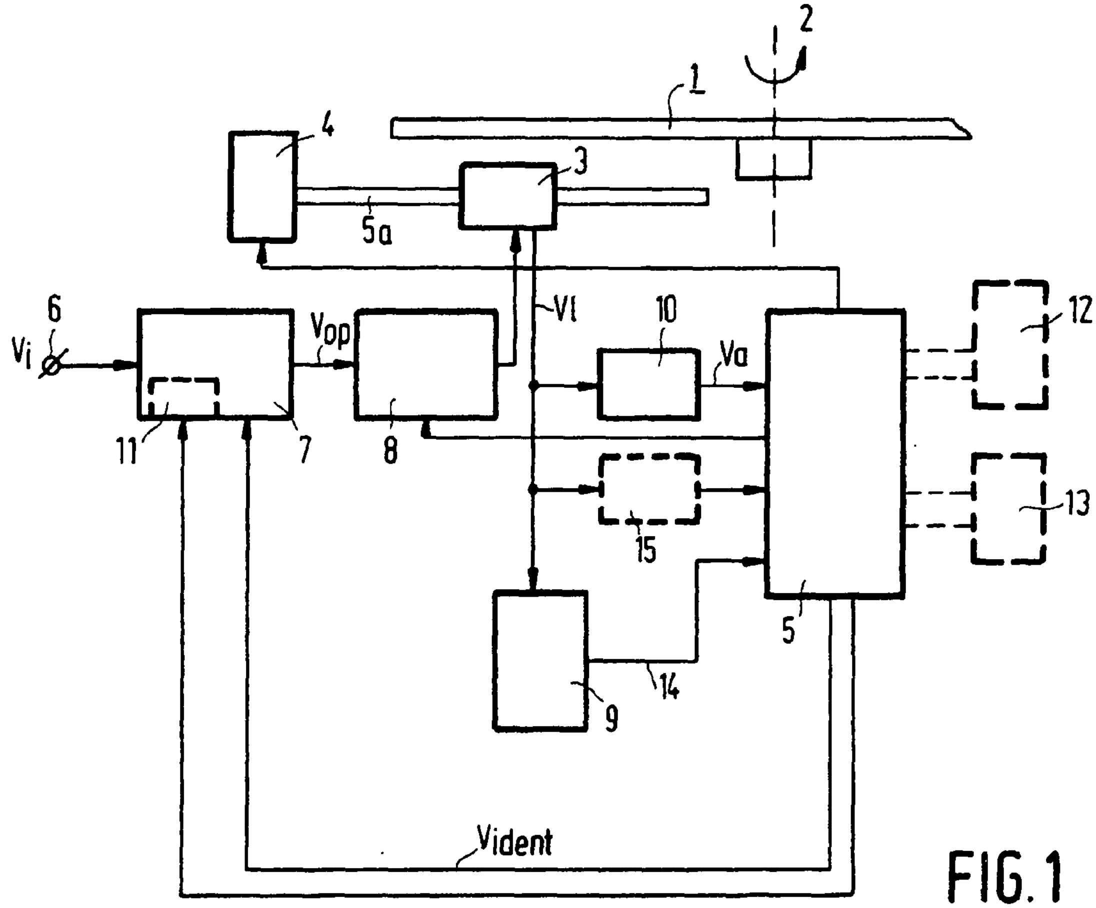

FIG.1

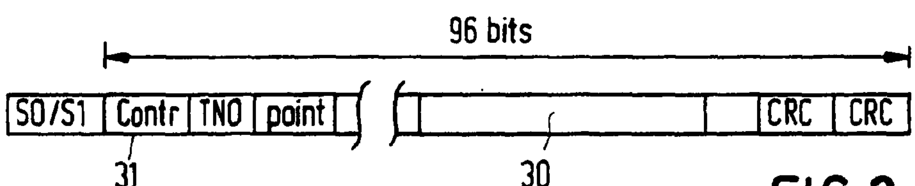

FIG.3

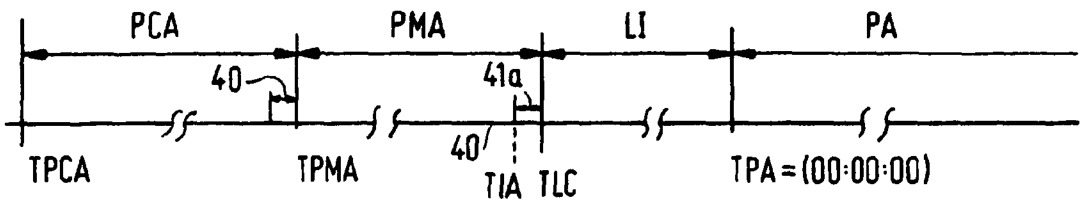

FIG.4

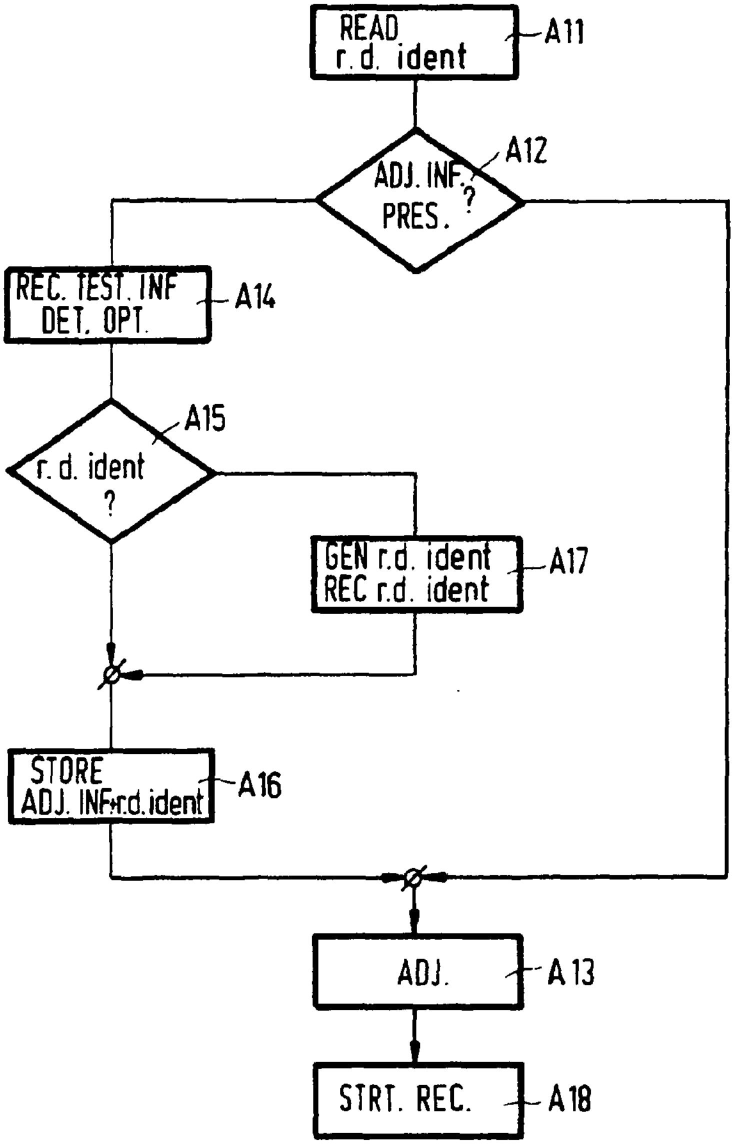
READ
r.d. ident
A11
ADJ. INF. PRES. ?
A12
REC. TEST. INF
DET. OPT.
A14
r.d. ident
?
A15
GEN r.d. ident
REC r.d. ident
A17
STORE
ADJ. INF+r.d. ident
A16
ADJ.
A 13
STRT. REC.
A18

FIG.2

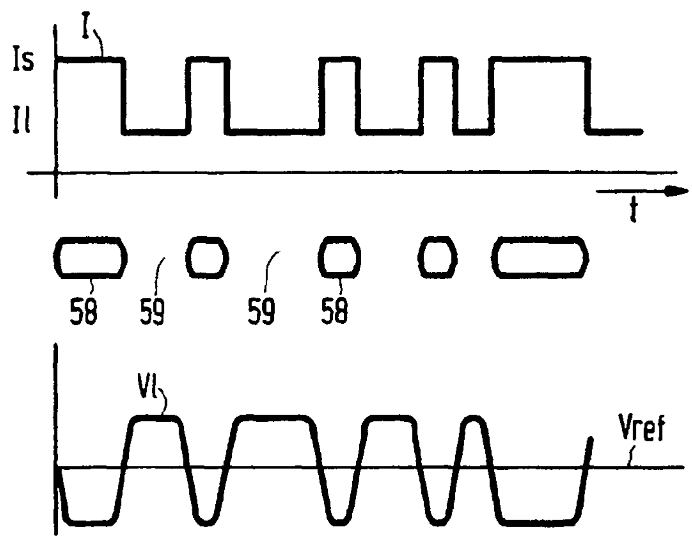
I
Is
Il
t
58
59
59
58
Vl
Vref

FIG.5

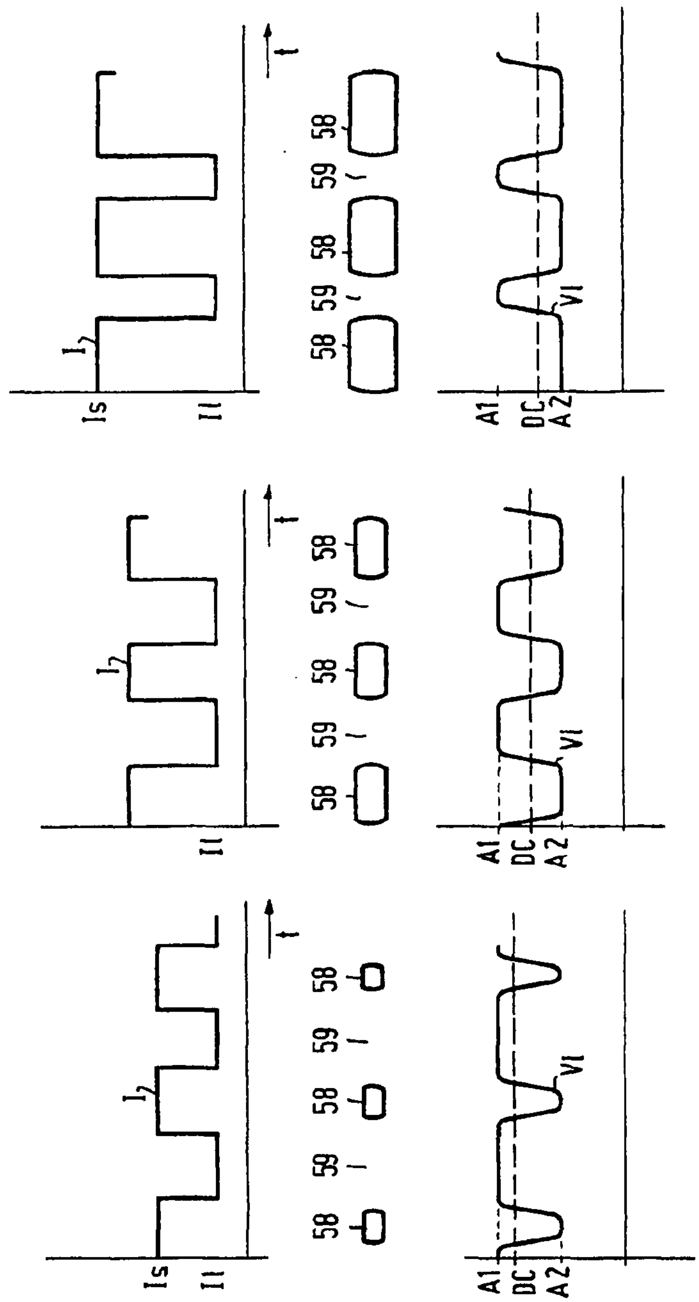

FIG.6a

FIG.6b

FIG.6c

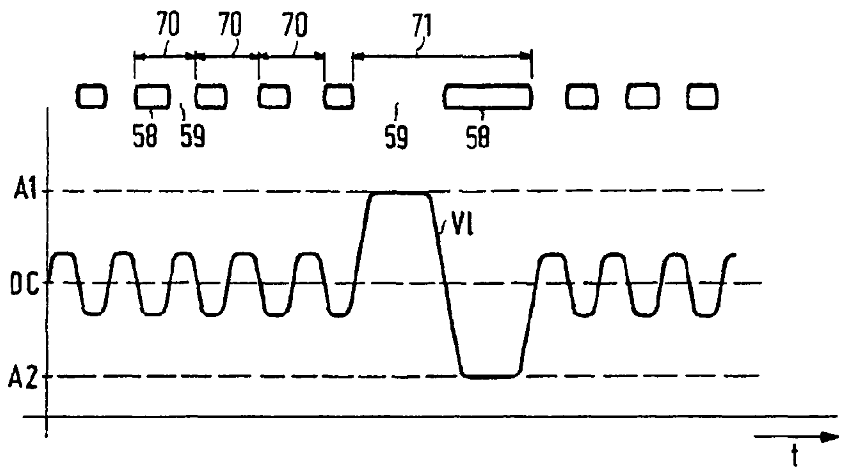

FIG.7a

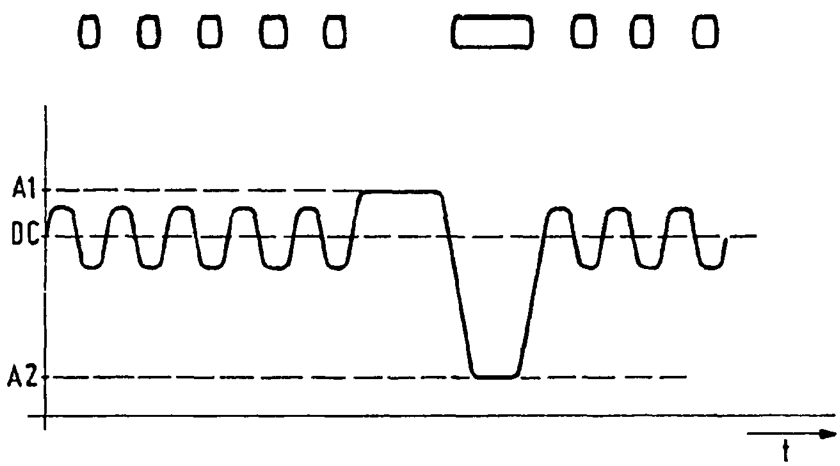

FIG.7b

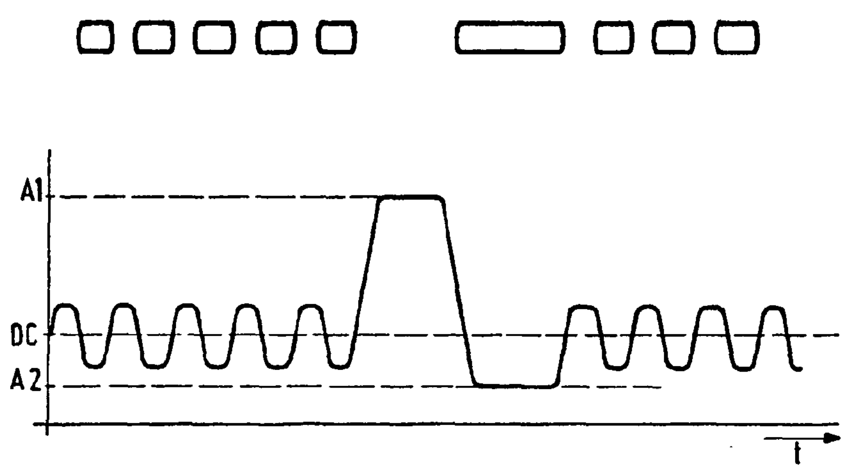

FIG.7c

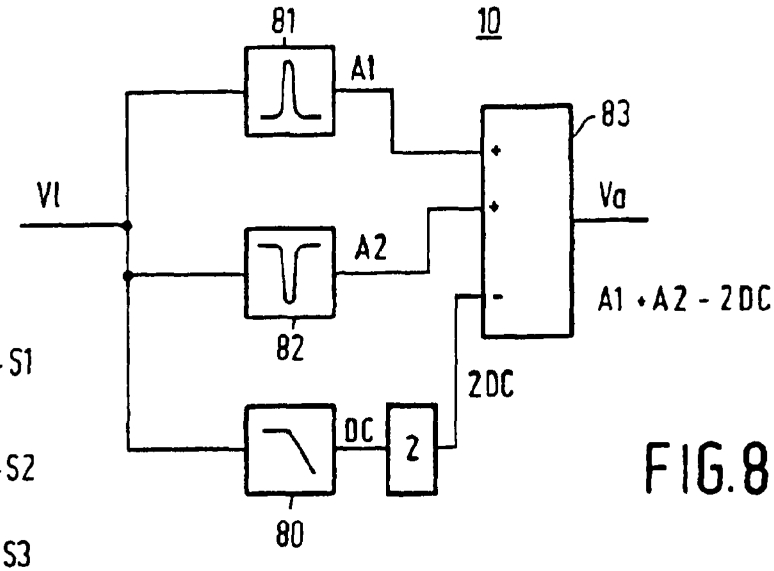
81
10
A1
83
Vl
Va
A2
A1 + A2 - 2DC
82
2DC
DC
2
80

FIG.8

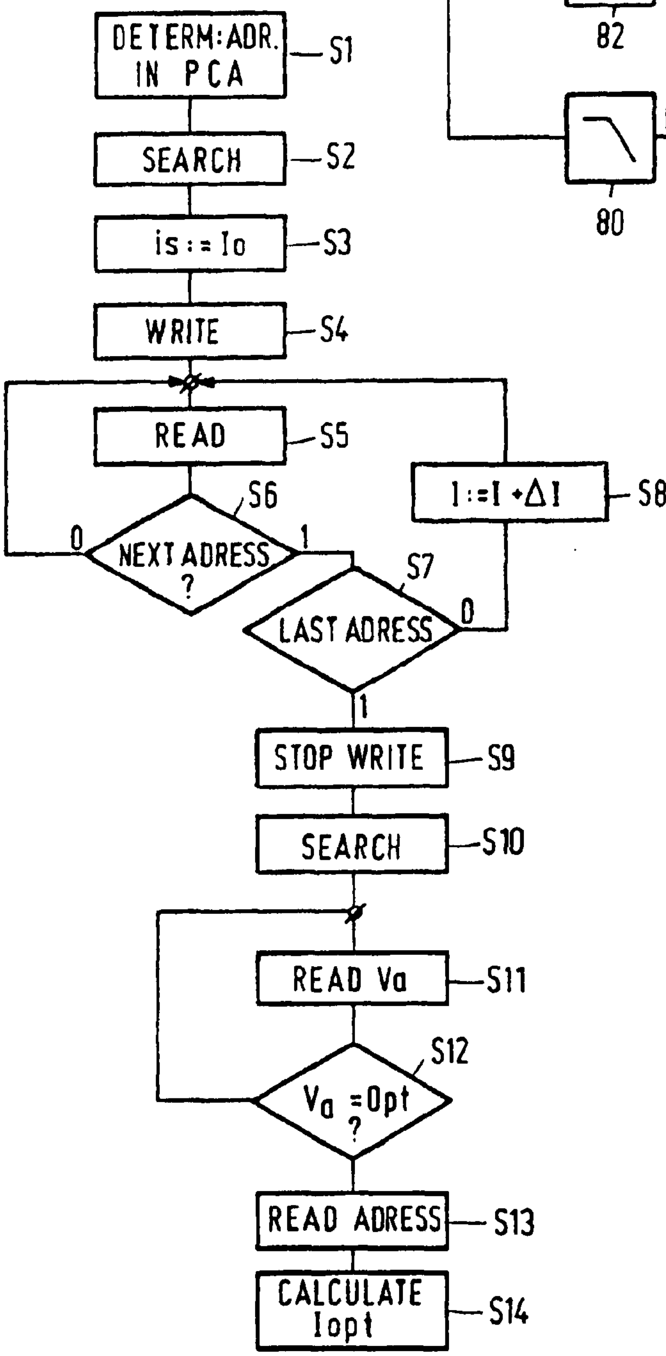
DETERM:ADR. IN PCA
S1
SEARCH
S2
is := Io
S3
WRITE
S4
READ
S5
S6
I := I + ΔI
S8
0
NEXT ADRESS ?
1
S7
LAST ADRESS
0
1
STOP WRITE
S9
SEARCH
S10
READ Va
S11
S12
Va = Opt ?
READ ADRESS
S13
CALCULATE Iopt
S14

FIG.11

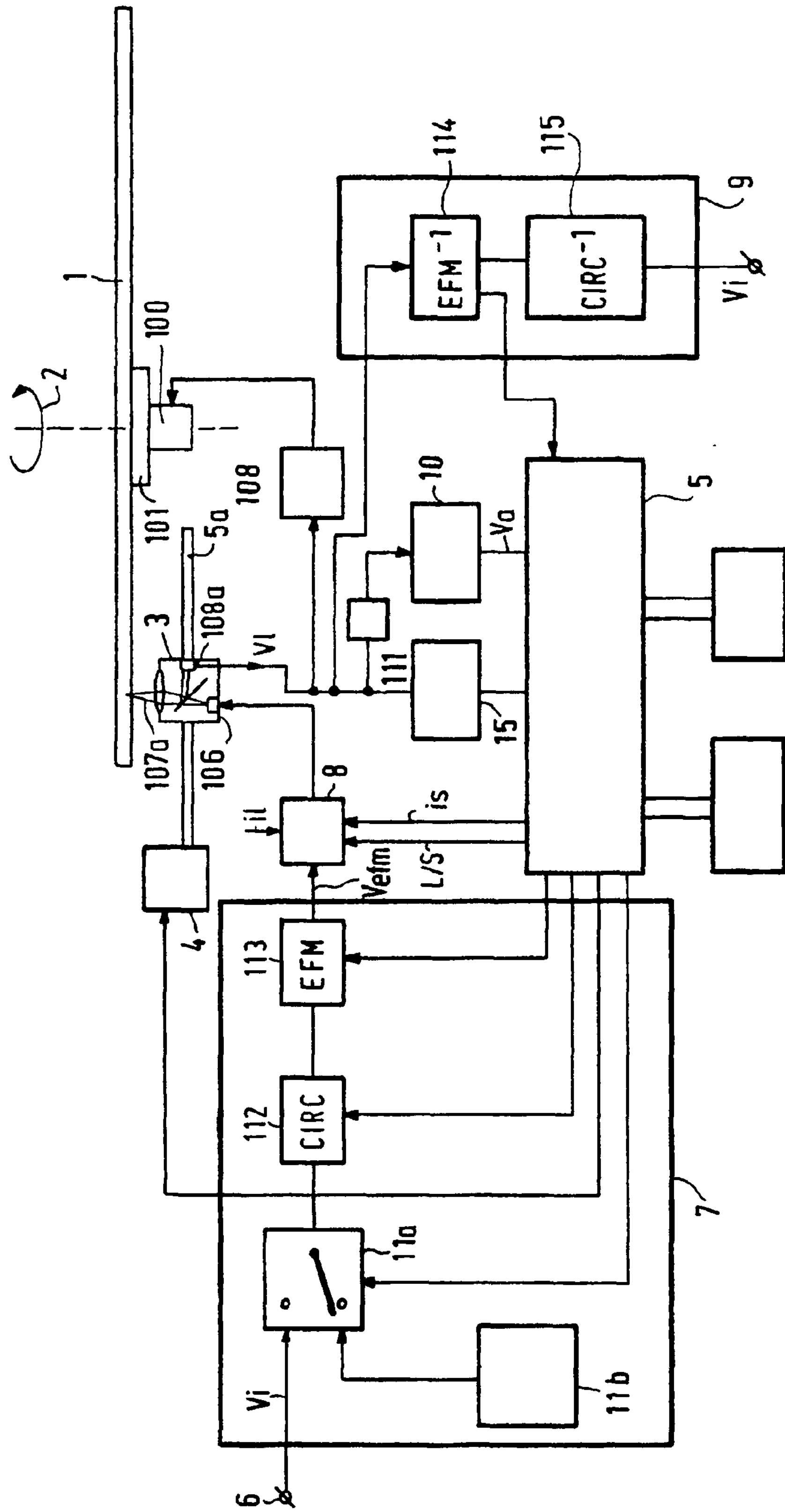
1
2
100
101
108
5a
3
108a
Vl
107a
106
4
8
Iil
is
L/S
Vefm
10
Va
111
15
5
13
12
9
114
115
EFM^{-1}
$CIRC^{-1}$
Vi
113
EFM
112
CIRC
7
11a
11b
Vi
6

FIG.9

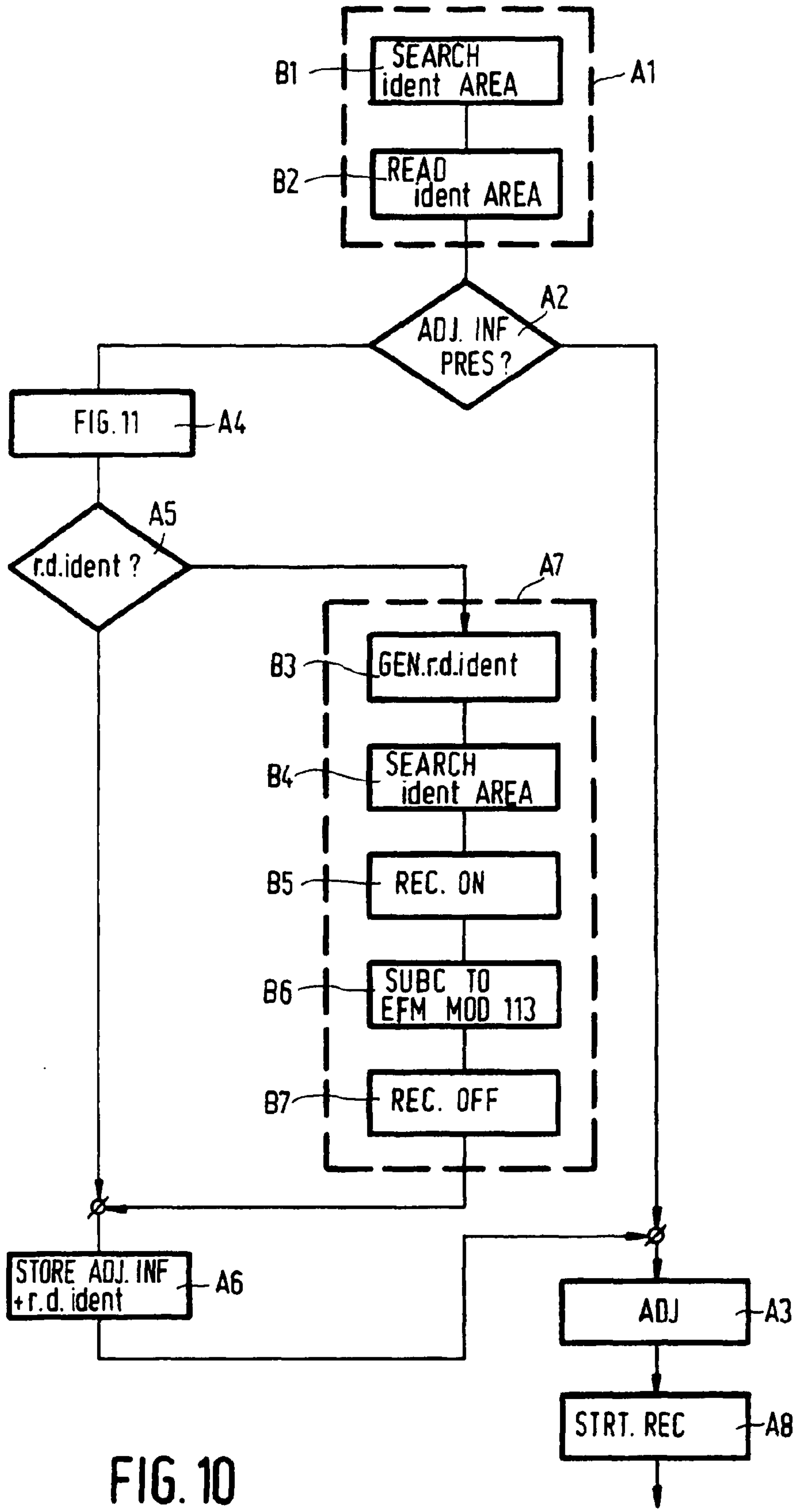
SEARCH ident AREA
B1
A1
READ ident AREA
B2
ADJ. INF PRES ?
A2
FIG. 11
A4
r.d.ident ?
A5
A7
GEN.r.d.ident
B3
SEARCH ident AREA
B4
REC. ON
B5
SUBC TO EFM MOD 113
B6
REC. OFF
B7
STORE ADJ. INF +r.d. ident
A6
ADJ
A3
STRT. REC
A8

FIG. 10

European Patent Office

EUROPEAN SEARCH REPORT

Application Number

EP 91 20 0257

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
X,A	EP-A-0 126 682 (THOMSON-CSF) * abstract; claims 1, 9-11 * * page 2, line 23 - page 3, line 10 @ page 3, line 30 - page 4, line 31 @ page 16, line 13 -page 17, line 16 * – – –	1,2-4	G 11 B 7/007
A	EP-A-0 265 849 (HITACHI LTD) * the whole document * – – – – –	1-4	

TECHNICAL FIELDS SEARCHED (Int. Cl.5)
G 11 B

The present search report has been drawn up for all claims

Place of search	Date of completion of search	Examiner
The Hague	10 May 91	BENFIELD A.D.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same catagory
A : technological background
O : non-written disclosure
P : intermediate document
T : theory or principle underlying the invention

E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

US005617405A

United States Patent [19]

Victora et al.

[11] Patent Number: 5,617,405

[45] Date of Patent: Apr. 1, 1997

[54] **OPTICAL RECORDING MEDIUM HAVING AT LEAST TWO SEPARATE RECORDING LAYERS OF DIFFERENT WRITING TEMPERATURES**

[75] Inventors: **Randall H. Victora**, Rochester; **Giuseppe Farruggia**, Webster, both of N.Y.

[73] Assignee: **Eastman Kodak Company**, Rochester, N.Y.

[21] Appl. No.: **611,266**

[22] Filed: **Mar. 5, 1996**

[51] **Int. Cl.**^{6} **G11B 3/74**

[52] **U.S. Cl.** **369/275.1**; 369/94; 369/286

[58] **Field of Search** 369/275.2, 275.1, 369/275.3, 275.4, 275.5, 14, 272, 273, 280, 281, 286, 94

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5,499,231	3/1996	Fennema et al.	369/275.1
5,513,170	4/1996	Best et al.	369/275.1

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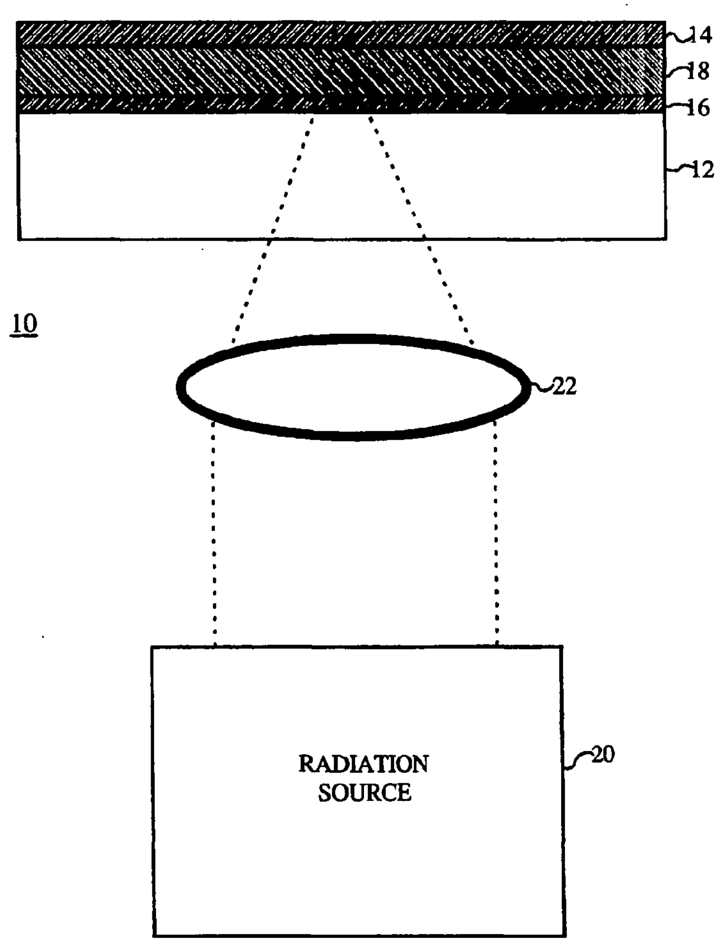
Primary Examiner—Tan Dinh
Attorney, Agent, or Firm—Raymond L. Owens

[57] **ABSTRACT**

An optical storage device comprising at least two spaced apart recording layers, a spacer layer separating by being positioned between alternating recording layers, and each recording layer including a material responsive to a beam of radiation from a source to record information and at least one recording layer having a different write temperature selected to improve recording performance parameters.

7 Claims, 1 Drawing Sheet



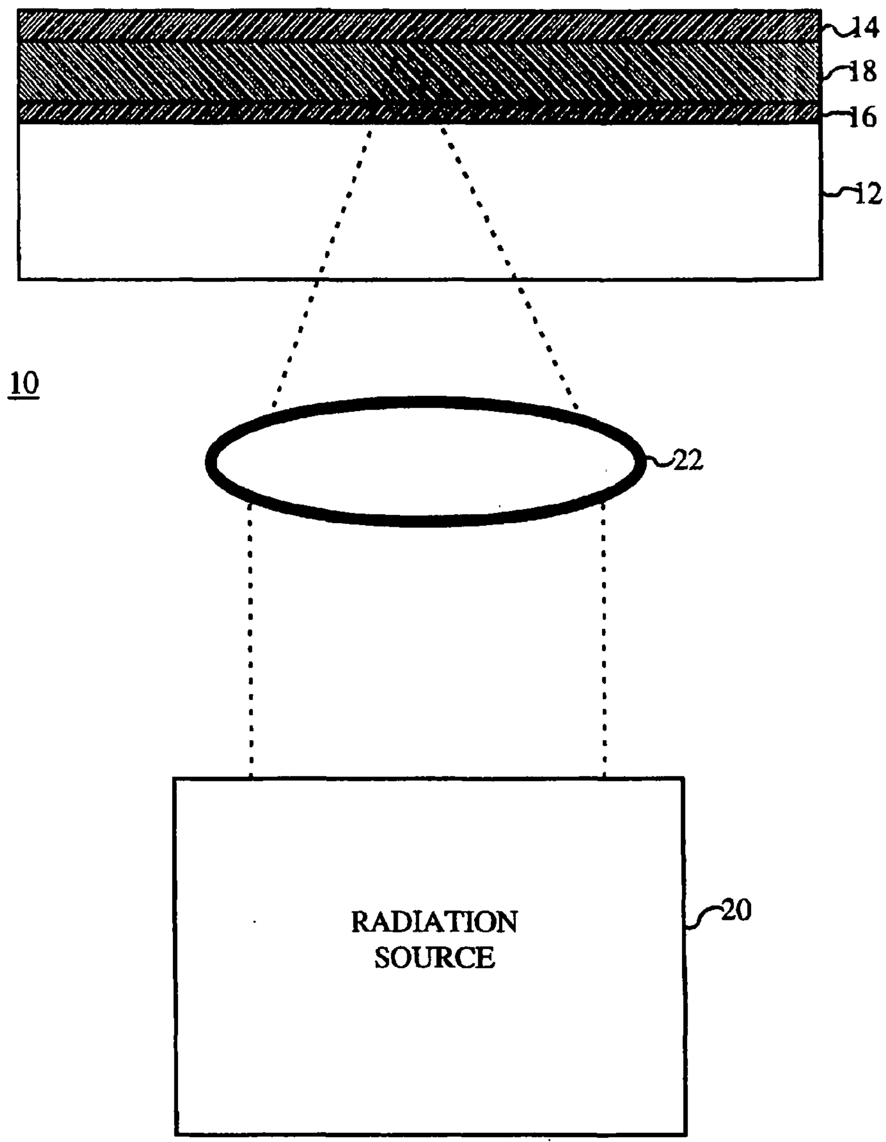


Fig. 1

OPTICAL RECORDING MEDIUM HAVING AT LEAST TWO SEPARATE RECORDING LAYERS OF DIFFERENT WRITING TEMPERATURES

FIELD OF THE INVENTION

The present invention relates to optical storage devices which have multiple recording layers.

BACKGROUND OF THE INVENTION

Optical storage devices such as optical disks and optical tape are becoming more and more extensively used. It is, of course, highly desirable to increase the storage capacity and other performance parameters such as signal to noise and storage density.

A multilayer optical storage device is set forth in SPIE Vol. 2338, p. 247, 1994 (K. A. Rubin, H. J. Rosen, W. W. Wang, W. Imaino, and T. C. Strand). The recording layers consist of two or more recording surfaces spaced sufficiently far apart that each surface can be recorded and read independently. A two layer medium might be expected to offer twice the density of a conventional single layer medium. Generally, this is not true because the return light beam is severely attenuated relative to the return light beam found in a conventional single layer medium. For example, an attempt to read a layer that is not the layer closest to the radiation source requires the light to pass through the other layers with a consequent loss of intensity. Even reading the layer closest to the radiation source does not generate the maximum possible return beam because this layer must be optimized for transparency, not merely optimal return beam. It might, for example, be very thin and unreflective compared to a conventional single layer.

This severe attenuation of the return light beam substantially reduces the carrier. More significantly, the carder to noise ratio (CNR) also decreases because, unlike the carrier, the noise power usually consists of large contributions from sources not directly proportional to the beam intensity and thus not proportionately reduced by the attenuation. This reduction in CNR reduces the storage density of the layer and the overall storage device.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a multiple recording layer storage device which has improved performance parameters.

The object is achieved in an optical storage device, comprising:

a) at least two spaced apart recording layers;

b) a spacer layer separating by being positioned between alternating recording layers; and

c) each recording layer including a material responsive to a beam of radiation from a source to record information and at least one layer having a different write temperature selected to improve recording performance parameters.

Advantages

An important advantage of the invention is increasing the carder, at the same available power of radiation source, relative to a device employing only a single write temperature. This is a consequence of the enhanced read power that can be used in reading the layers that have increased write temperature. If, for example, the write temperature of layer i is adjusted so that the optimum recording power (ORP) of layer i matches that of the layer most distant from the radiation source, then the increase in the available carrier can be estimated to equal the ORP of the layer most distant from the radiation source divided by the ORP of layer i in the absence of the invention, assuming that the ratio of the read power to the ORP is approximately the same for all layers, as is frequently the case. Noise can be typically expected to arise from a variety of sources; in most cases, the noise will increase with incident light power much less rapidly than the carder. Therefore, this invention is also expected to increase the Carder to Noise Ratio (CNR). This will further allow marks to be placed closer together than would otherwise be the case. Therefore, the invention is expected to increase the storage density of the device.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagramatic view of an optical storage device having two spaced apart optical recording layers.

DETAILED DESCRIPTION OF THE INVENTION

Turning first to FIG. 1, there is shown an optical storage device **10**. The device **10** includes a substrate **12** which typically can be made from polycarbonate or glass. There are two spaced apart recording layers **14** and **16**. These recording layers will be discussed in more detail hereinafter. A spacer layer **18** is provided between the two recording layers. The spacer layer typically can be made from a transparent organic material (which does not interact with the wavelength of the radiation source) or air. A source of radiation **20** provides a beam of radiation which is focused by a focusing arrangement shown as a single lens **22**. In the example shown, the radiation beam is focused on the surface of the recording layer **14**. Of course, when recording is to take place on the layer **16**, the beam will be focused on that layer. It will be understood that although two recording layers are shown, the present invention can include three or more recording layers with alternate recording layers being spaced apart by a spacer layer. Moreover, the recording process can take place through the non-substrate surface of the storage device and, in such a situation, the substrate could be opaque. Furthermore, the recording layers can be accompanied by other nonwritable layers such as dielectrics for optical enhancement or metals for reflecting fight.

In accordance with the present invention, an optical storage device includes multiple recording surfaces such that individual surfaces have differing write temperatures. The recording surfaces can contain rewritable materials such as magneto-optically active materials for which the write temperature is the temperature at which the magnetization can be reversed or erasable phase change materials for which the write temperature might be the temperature needed to form the higher temperature phase. The recording surfaces can also contain write-once materials such as write-once phase change where the write temperature might be the temperature of crystallization or ablative materials where the write temperature is the temperature necessary for ablative recording. It is recognized that the write temperature can depend on the speed of the recording process and, in consequence, the media velocity relative to the record beam.

In accordance with one aspect of the invention, the write temperature of the recording layer nearest the radiation source should be the highest with a monotonic decrease in write temperature with distance from the radiation source.

Advantageously, for more optimum results, the write temperatures can be selected such that the Optimum Recording Power (ORP), as measured by the light emitted from the radiation source, is identical for all layers. (Depending on the application, the ORP might be the power where the second harmonic of the signal is minimized relative to the first harmonic or the power where offset from the desired mark size is zero.) In another aspect of the invention the write temperatures are selected so that the ORP of layer i measured without the presence of the other layers is equal to the ORP of the layer most distant from the radiation source (as measured without the presence of the other layers) divided by the product of all the transmission coefficients for the layers inclusively between the layer second most distant from the source and layer i. This can be expressed by the following equation:

$$(ORP)_i = ORP_n/(T_{n-1} \ldots T_i)$$

wherein:

- i is a number from 1 to n;
- i=1 corresponds to the layer nearest to the light source;
- n is the number of recording layers;
- ORP_i is the optimum recording power of layer i measured without the presence of the other layers; and
- T_i is a transmission coefficient for layer i.

Alternatively, the difference between the write temperature of layer i and the ambient temperature can be selected to equal the difference between the write temperature of the layer most distant from the radiation source and the ambient temperature both divided by the product of all the transmission coefficients for the layers inclusively between the layer second most distant from the radiation source and layer i. This condition is equivalent to the previous two criteria if the ORP of layer i divided by the difference between the write temperature and the ambient temperature is equal for all layers. This can be expressed by the following equation:

$$(\theta_i - \theta_A) = (\theta_n - \theta_A)/(T_{n-1} \ldots T_i)$$

wherein:

- θ_i is the write temperature of layer i;
- θ_A is the ambient temperature; and
- T_i is a transmission coefficient for layer i.

Although the implementation of multiple write temperatures alone will increase the performance of the storage device, further benefits can be be gained by a concomitant change in the optical properties of the individual layers. In particular, an optimal configuration would require that layers near the radiation source permit more transmission (accepting the consequent loss in signal) than would be found in a device optimized for a single write temperature on all layers.

Six examples of the implementation of the invention are now set forth. A 780 nm radiation source was used for generating both the measured and predicted data. For the purpose of calculating the extent to which the invention improves the carrier, in the first five examples it will be assumed that the record power (as measured for each layer in the absence of the other layers) and the optimum read power (as measured for each layer in the absence of the other layers) are proportional to the difference between the write temperature and ambient temperature. Deviations from this rule may be caused by layers having, for example, differing thermal transport characteristics and may increase or decrease the precise value of carrier enhancement offered by the invention. These deviations do not affect the general principle of the invention.

Example A: Consider a two-layer disk, employing dye as the active layer, arranged in a structure such that the transmission and reflection coefficients of the layer nearest the radiation source (layer **1**) are 68% and 18%, respectively and the second layer (layer **2**) has transmission and reflection coefficients of 20% and 30%, respectively. If the differences between the write temperature and the ambient temperature are chosen to follow a ratio of 1.47=1.0/0.68 and 1.0 for layers **1** and **2** respectively, then the carrier of layer **1** will increase by 3.3 dB=20 log 1.47 with no increase in maximum power demanded from the laser. The carrier of layer **2** will not change.

Example B: Consider a two layer disk where the thickness of layer **1** has been adjusted to distribute the enhancement provided by the invention over both layers. The transmission and reflection coefficients for the thinned layer **1** become 74% and 14%, respectively. This increases the carder of layer **1** by 1.2 dB and layer **2** by 1.5 dB provided that the carrier is proportional to the reflectivity. For magneto-optic materials the increase from layer 1 would be different.

Example C: Consider a four-layer disk for which the transmission coefficients for layers **1–4** are 84%, 79%, 68%, and 0%. The reflection coefficients for layers **1–4** are 8%, 11%, 18%, and 40%. The differences between the write temperature and the ambient temperature are chosen to follow a ratio of 2.22=1.0/(0.84*0.79*0.68), 1.86=1.0/(0.79*0.68), 1.47=1.0/0.68, and 1.0 for layers **1–4**, respectively. If the write temperatures are required to be the same on all layers, then the carrier drops by 6.9 dB, 5.4 dB, and 3.3 dB on layers **1-3**, respectively.

Example D: Consider a two-layer disk employing Co/Pt in the magneto-optic recording layers, the layers being separated by a spacer layer with refractive index of 1.3. The transmission coefficients are 56% and 12% for layers **1** and **2**, respectively. The reflection coefficients are 6% and 44% for layers **1** and **2**, respectively. The maximum Kerr rotations are 1.76 and 0.69 for layers **1** and **2**, respectively. (Film thicknesses are **42Å** and **200Å**) If the differences between the write temperature and ambient temperature are chosen to follow a ratio of. 1.79=1.0/0.56 and 1.0 for layers **1** and **2** respectively, then the carrier of layer **1** o will increase by 5.1 dB=20 log. 1.79 with no increase in maximum power demanded from the laser. The carrier of layer **2** will not change.

Example E: Consider a four-layer disk employing Co/Pt in the magneto-optic recording layers, the layers being separated by a spacer layer, with refractive index of **1.3**. The transmission coefficients are 75%, 71%, 56%, and 12% for layers **1–4**, respectively. The reflection coefficients are 1%, 3%, 8%, and 44% for layers **1–4**, respectively. The maximum Kerr rotations are 2.52, 1.57, 1.39, and 0.69 for layers **1–4**, respectively. (Film thicknesses are **21Å**, **23Å**, **42Å**, and **200Å**.) The differences between the write temperature and ambient temperature are chosen to follow a ratio of 3.35=1.0/(0.75*0.71*0.56), 2.52=1.0/(0.71*0.56), 1.79=1.0/0.56, and 1.0 for layers **1–4**, respectively. If the write temperatures are required to be the same on all layers, then the carrier drops by 10.5 dB, 8.0 dB, and 5.1 dB on layers **1–3**, respectively.

Example F: Co/Pt superlattice is a magneto-optically active layer particularly suitable for implementation of this invention. A two-layer disk was made using a recording material consisting of 0.22 nm Co layers sandwiched by 0.7 nm Pt layers. The semitransparent layer **1** of this disk is 4.2 nm thick and layer **2** is 20 nm thick. Recording experiments show that the threshold of layer **1** is approximately 2.4 mW with an optimum record power of approximately 5.5 mW.

The threshold of layer **2** was approximately 3.3 mW with an optimum record power of approximately 7.0 mW. Layer **1** produced a carder of −2.8 dB, a 30 kHz slot noise of −44.5 dB, and CNR of 41.7 dB when measured using a 0.5 NA lens, a velocity of 3 M/s, a recording frequency of 1.57 Mhz, a bandwidth of 30 kHz, and a read power limited to 1.5 mW to reduce erasure during read. Following the teaching of the invention a second disk is fabricated using the same composition for layer **2**, but using a recording material consisting of 0.35 nm Co layers sandwiched by 0.7 nm Pt layers for layer **1**. This increases the threshold of layer **1** to approximately 3.3 mW and the optimum recording power to approximately 7 mW. The carrier was now increased to 0.5 dB, the slot noise is approximately the same at −44.6 dB, and the CNR is increased to 45.1 dB, all under the same conditions as used for the unimproved layer **1** except that the read power was increased to 2.0 mW because the threshold for recording is higher. Accidental improvements to layer **1** owing to extraneous effects such as improved coercivity or Kerr rotation with higher Co content were demonstrated to provide only 0.3 dB of this improvement in CNR by remeasuring the improved layer **1** at the reduced read power (1.5 mW) suitable for the original layer **1**. Therefore, implementation of the invention has generated an additional 3 dB of CNR with no requirement of higher maximum laser power.

A feature of the invention is that it increases performance in the presence of optically enhancing layers needed to generate adequate carrier for some recording materials.

An alternative method is to vary the thermal properties of the material surrounding the recording layer. For example, the recording layer nearest the light source can be surrounded by thermally conducting materials that will have the effect of decreasing the sensitivity of the layer to the radiation power and the farther recording layers can be surrounded by thermally insulating materials that will have the effect of increasing the sensitivity.

The invention has been described in detail with particular reference to certain preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention.

PARTS LIST

10 optical storage device
12 substrate
14 recording layer
16 recording layer
18 spacer layer
20 radiation source
22 single lens

We claim:

1. An optical storage device, comprising:

a) at least two spaced apart recording layers;

b) a spacer layer separating by being positioned between alternating recording layers; and

c) each recording layer including a material responsive to a beam of radiation from a source to record information and at least one layer having a write temperature different than other recording layers and selected to improve recording performance parameters.

2. The optical storage device of claim **1** wherein the write temperature of the recording layer nearest the radiation source is higher than the write temperature of the recording layer furthest from the radiation source with a monotonic decrease in write temperature as the distance from the radiation source increases.

3. The optical recording device of claim **1** wherein the write temperatures of each recording layer is selected such that the optimum recording power as measured by the radiation emitted from the source is substantially identical for all recording layers.

4. The optical recording device of claim **1** wherein the write temperature of each recording layer is selected so that the following equation is satisfied:

$$(ORP)_i = ORP_n/(T_{n-1} \ldots T_i)$$

wherein:

i is a number from 1 to n;

i=1 corresponds to the layer nearest to the light source;

n is the number of recording layers;

ORP_i is the optimum recording power of layer i measured without the presence of other layers (spacer and recording); and

T_i is a transmission coefficient for layer i.

5. The optical recording device of claim **1** wherein the write temperature for each layer is selected from the following equation:

$$(\theta_i - \theta_A) = (\theta_n - \theta_A)/(T_{n-1} \ldots T_i)$$

wherein:

θ_i is the write transmission temperature of layer i;

θ_A is the ambient temperature;

i is a number from 1 to n;

n is the number of recording layers;

i=1 corresponds to the layer nearest to the light source; and

T_i is a transmission coefficient for layer i.

6. The optical recording device of claim **1** wherein the recording layers nearest the radiation source permit more transmission than those furthest from the source.

7. The optical recording device of claim **1** wherein the recording layer materials are selected from the group consisting of:

a) magneto-optic;

b) erasable and non-erasable phase change; and

c) ablative.

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